7th Annual
AIAA/Utah State University
Conference on Small Satellites
September 13-16, 1993
Logan, Utah

PLUTO MISSION PROGRESS: INCORPORATING ADVANCED TECHNOLOGY

Robert L. Staehle*, Stephen Brewster, Doug Caldwell, John Carraway, Paul Henry, Marty Herman, Glen Kissel, Shirley Peak, Vince Randolph, Chris Salvo, Leon Strand, Rich Terrile, Mark Underwood, Beth Wahl, Stacy Weinstein

Jet Propulsion Laboratory,
California Institute of Technology
Pasadena, CA 91109 USA

and

Elaine Hansen
University of Colorado
Colorado Space Grant Consortium
Boulder, CO 80309 USA

Abstract

A development team at the Jet Propulsion Laboratory (JPL) is designing a mission to send two very small spacecraft to Pluto and Charon to complete the initial reconnaissance of our solar system. The two probes, each carrying four science instruments, will obtain information on both hemispheres of Pluto and Charon in the form of visual images, infrared and ultraviolet data, and radio science. This paper briefly describes the mission design and spacecraft instrumentation and subsystems, and reports on the current progress to implement advanced technology in reducing spacecraft mass and power requirements. Cost, schedule and performance, in that priority, are the primary design drivers.

The goal of the mission is to deliver two 110 kg spacecraft costing less than $400M for both, on a direct trajectory to the Pluto-Charon system taking approximately 7-8 years to arrive before the collapse of Pluto's atmosphere. Contract and in-house work has been in progress to provide breadboard proof-of-concept hardware and software contributing toward the lower mass goal and reducing costs. Results are reported for candidate scientific payload instruments, a composite structure, advanced antenna, significantly smaller electronics packaging, high efficiency thermal-to-electric converters for the radioisotope heat sources and other candidate areas for mass, power and size reduction within strict cost limits.

*Manager, Pluto Preproject

Mission Background

Referred to as the double-planet with its satellite Charon, Pluto is the only known planet in our Solar System that has yet to have a visiting spacecraft reveal some of its secrets,

Commissioned by the S. Postal Service, artist Ron Miller created stamps for the Moon, Earth, and all the other planets depicted with spacecraft. The tenth and last stamp in the set showed Pluto with no spacecraft and the taunting caption, "PLUTO - NOT YET EXPLORED." Going to Pluto is not a new idea, but it was from this inauspicious reminder in October, 1991 that the current mission to Pluto was born.

Pluto remains the "Mount Everest" of Solar System exploration. It is the farthest, coldest and hardest planet to get to. It was thought that with the present technology and economic environment, the. end-to-end mission would take too long and cost too much to be successful. A mission of this scope indeed presents many challenges [1,2].

The Outer Planets Science Working Group (OPSWG), a charter group of leading planetary scientists, looked at small and large missions to Pluto and reported their findings to the National Aeronautics and Space Administration (NASA) as early as May, 1991. In subsequent meetings with NASA, OPSWG formally endorsed the JPL concept of a dual Pluto flyby with very small spacecraft.

in April, 1992, in response to increasing economic stresses and social concerns Daniel Goldin, NASA's administrator, asked its members to find faster, better and cheaper ways of doing the business of space science. If NASA could design and fly missions that produce good science for billions of tax-payers' dollars, couldn't we get smarter and fly missions that produce good science for hundreds of millions fewer dollars? Upon learning of the exciting, new Pluto mission, with its tiny spacecraft, fast trajectory and attractive price tag, he gave it his enthusiastic endorsement but warned that the 164 kg spacecraft that designers had envisioned would have to shed some kilograms in order to fly. This directive from NASA headquarters, reducing spacecraft mass, would become the driver for developing new technologies that would enable a 100 kg class spacecraft to do the same science as a more massive one, and to do it for less cost to the tax payers. Some new technologies would then spin-off into other private sector industries providing a broader based benefit. This latest mission to fly to Pluto would seem a likely vehicle in which to apply this advanced technologic effort.

FY92 Baseline [1]

The preliminary FY92 baseline for the Pluto Fast Flyby mission was designed to return valuable

MASS BUDGET (kg)	
Telecom	25.2
Power	23.2
ACS	2.7
Command & Data	7.0
Structure	20.0
Propulsion	20.1
Thermal	4.0
Instrument	9.0
Subtotal	111.2
Cont. (27%)	29.5
Monopropellant	24.6
Total Wet S/C	165.3

Additional mass margin exists in the mission design; additional wet spacecraft mass results in slightly longer flight times.

POWER BUDGET	(W)
Telecom	15.0
Power	12.7
ACS	11.5
Command/Data	6.0
Propulsion	1.5
Thermal	1.0
Science	6.0
Subtotal	53.7
20% Cont.	10.7
Total	64.4

* Power shown is for encounter.
* RTG generates 65 W at encounter, 63.8 W 10 years from launch.
* 62.8 W required for post encounter downlink.

PERFORMANCE

POINTING	~1.5 mrad 10 μrad over 1 sec
DOWNLINK DATA RATE	~40 bps @ X-band; 34 m BWG @ 31 AU"
DATA STORAGE	400+ Mbit
DELTA-V Capability	350 m/s
HEIGHT ~1.2 m	BUS DIAMETER 0.5 m
ANTENNA DIAMETER	1.47 m

Table 1. 1992 Baseline Mass -Power Budget

global scientific data from Pluto and Charon as soon as possible and to do it within a strict cost cap.

Plans are to launch two spacecraft on separate vehicles in 1999 on a direct trajectory to pass within ~ 15,000 km of Pluto and Charm in 2007, obtain scientific data and transmit that data to Earth during the year following the encounter. The cost cap for this mission, (FY92)$400M for the mission development including two spacecraft and their science payloads, plus mission operations from launch through 30 days after launch, appears feasible. Cost caps for mission operations during the cruise and encounter stages have yet to be determined but will be kept down by limiting the size of the operations crew and by limiting cruise operations. Additional costs will be incurred for launch vehicles, the radioisotopic power source (RPS), and tracking by the Deep Space Network (DSN). If the costs exceed the amount which Congress initially approves, the entire effort is likely to be canceled. NASA will choose when to submit the Pluto mission for a "new start" in the Federal budget.

Advanced Technology Insertion

The so-called FY92 Baseline Pluto spacecraft was designed at a mass of 165 kg, including reserves and propellant. It was felt that this relatively conservative design approach would benefit from more advanced technology to perform the same functions at lower mass, shortening trip time and stimulating new technology applications for deep space missions.

NASA's office of Advanced Concepts and "1'ethnology (OAC'l') provided funds for research and demonstration of new technologies that will benefit the Pluto mission in meeting its goals. Within a process called Advanced Technology Insertion (ATI), the mission development team issued a request for information (RFI) and invited over 1200 contacts in industry, academia, and Federal laboratories to look at the mission constraints of cost, schedule and reduced mass and to help identify candidate new technologies that might be included in the conceptual design efforts. Team leaders specifically made it clear to the contracting companies that paper studies were not the desired product. Tbc team wanted proof-of-concept hardware or software showing that a particular technology could be developed for incorporating into the Pluto mission within strict cost and performance goals. Preliminary ATI work has resulted in delivery of first breadboard products in August, with subsequent deliveries through May, 1994. New technologies for the Pluto mission will be rigorously pursued to about mid-1995 when a technology freeze will be imposed. The remainder of this paper illustrates specific areas in the mission development where advanced technology is expected to show benefits, In some cases, technology demonstration work now under contract will not produce hardware of sufficient maturity to constitute an acceptable cost and schedule risk for the mission within available resources. In these cases, to be decided over the next several months, certain technologies may be left to others to bring to flight status.

Science Instruments

Science goals for this mission have been arranged into three classes. The first being class 1a representing the "must do" science objectives. These include the characterization of Pluto's and Charon's global geology and morphology, surface compositional mapping, and the characterization of Pluto's neutral atmosphere. Class 1 b and 1 c objectives will be attempted if still within the project constraints ['1'able 2], and if they can be satisfied using only the instruments carried to satisfy Category 1 a objectives.

The focussed Class 1 a science objectives arc a marked departure from the trend in planetary exploration toward larger spacecraft with very broad objectives. Likewise, the science instrument complement for such a mission reflects these limitations and has distinct similarities to earlier *Mariner* and *Pioneer* missions where the science payload was chosen to explore specific aspects of the planet in question. Later missions broadened the range of science addressed by each mission to a complete characterization of the planet and its environments and there appeared the consequent sharp rise in development time, flight time, payload complexity and cost. The Pluto-Charon mission, with some degree of time urgency and being cost-capped, has no such luxury and the science payload development will require both science teams and instrument designers to maintain a very strict discipline.

Because of the relatively short flight system development time, the science payload design must depend on technologies that arc relatively mature. However, the very ambitious mass and power allocations for the payload (7 kg, 6W) drive the design toward materials and architectures that have not been widely applied previously in planetary exploration and for which little or no flight experience exists. Achieving the delicate balance between bold application of new technology and acceptable risk will be a principle challenge of science payload development for the Pluto-Charon mission. As of the time of this writing, the top priority in payload development is the breadboard hardware showing with some degree of confidence that such a set of instruments can be developed, for a small expenditure.

The ATI breadboard hardware will illustrate concepts that employ advanced materials and electronics, novel optical arrangements, shaped optics and highly integrated packaging. Instrument design considerations need to address a low photon flux at Pluto's 30+ AU encounter distance, a very tenuous atmosphere and a relatively high flyby velocity, Albedo effects could also reduce the photon flux by another order of magnitude.

In an effort to better understand the opportunities and implications of the adaptation of advanced materials and architectures for the Pluto mission, a NASA Research Announcement (NRA) was issued early in 1993 for Pluto instrument concepts, the purpose of which is to insert advanced technology into the Pluto instrument design process. In April 1994, optical components, detectors, electronics ancl associated instrument designs arc to be delivered to the mission development team for evaluation, comparison, and usc in setting detailed interface specifications for a suite of flight instruments to be selected by a subsequent Announcement of opportunity (AO). The end result of the contracts issued under the 1993 NRA will be the mitigation of risk incurred later in the instrument development process by the inclusion of advanced technologies, and an increased confidence that the instrument complement necessary to achieve the science objectives can be accommodated within the constraints of the Pluto mission.

Under this ATI program,

PLUTO FAST FLYBY CORE SCIENCE OBJECTIVES
(No prioritization within categories)

Category Ia
- Characterize Global Geology and Morphology
- Surface Composition Mapping
- Characterization of Neutral Atmosphere Structure and Composition

Category Ib
- Surface and Atmosphere Time Variability
- Stereo Imaging
- High Resolution Terminator Mapping
- Selected High Resolution Surface Composition Mapping
- Characterization of Pluto's Ionosphere and Solar Wind Interaction
- Search for Neutral Species Including: 11, H_2, HCN, C_xH_y, and other Hydrocarbons and Nitriles in Pluto's Upper Atmosphere.
- Obtain Isotope Discrimination Where Possible
- Search for Charon's Atmosphere
- Determination of Bolometric Bond Albedos
- Surface Temperature Mapping

Category Ic
- Characterization of the Energetic Particle Environment
- Refinement of Bulk Parameters (Radii, Masses, Densities)
- Magnetic Field Search
- Additional Satellite and Ring Search

Table 2.. Core Science Objectives

breadboard hardware of critical instrument elements is being fabricated much earlier than usual in an effort to sort out the advantages and limitations of advanced materials and technologies for their application to deep-space planetary exploration. The experience gained will be available for application to the flight payload development.

The degree to which all the science instruments on-board the spacecraft will need to be combined into a single, highly integrated payload package is a matter that should be resolved by the ATI investigations. on the one hand, the sharing of various structural, optical and electronic elements among the optical instruments would seem to be highly desirable to meet the mass and power allocations and several investigators are pursuing such highly integrated approaches. On the other hand, if the adaptation of advanced materials and packaging techniques prove successful, mass may become less of a problem than other factors such as compromised performance, schedule, and cost "ripple" effects likely to arise in a highly integrated payload. If the latter factors become the dominant consideration, then a more modular approach would be preferable. In some cases, the adoption of an advanced material or design in one area may result in an undesirable effect in another area. An example is that light-weight structural material provides less radiation shielding than say, aluminum, thereby requiring the possible addition of more shielding material around sensitive electronic components, in turn, off-setting some of the mass advantages of the lightweight material.

A telescope with an aperture of about 7.5 cm to 12 cm, and a focal ratio of f/1 O to f/6.5 respectively, would achieve a monochromatic resolution of 1 km/lp at a sub-spacecraft range of 50,000 km *[2]*. CCDs with a 7.5 μm pixel dimension are now available and have been thoroughly characterized. This scenario would give the desired resolution, surpassing the resolution of the Hubble Space Telescope while the spacecraft is still four to six months way from encounter. Color imaging could certainly be achieved with very low-mass filter wheels, but investigators are exploring the idea of multiple CCD arrays utilizing fixed filters or beam splitters that don't rely on mechanical device,.s.

Spacecraft Subsystems

The Pluto Fast Flyby spacecraft has seven major subsystems: Telecommunications (Radio Frequency), Electrical Power and Pyrotechnics, Attitude Control, Command and Data, Structures and Mechanisms, Propulsion, and Thermal Control. The science instrument package is not labelled a subsystem because it is developed by a different team than the spacecraft team. The spacecraft team and the science instrument team coordinate to develop a complete spacecraft and instrument flight system.

Apart from the primary design driver of keeping the cost below $400M is the additional driver of getting to Pluto quickly to provide maximum scientific yield within strict payload constraints. This requirement impacts the spacecraft design in conflicting ways. "The reduced development schedule limits time needed for developing and testing new and advanced technologies. A balance must be struck between development cost and schedule, and operations cost and flight time. New technologies are investigated up to a "technology freeze" elate at which time the very best current applicable technology will be implemented.

The baseline spacecraft design for FY92 indicated a wet spacecraft mass of 164 kg. With the ATI process it was hoped to reduce the mass to about 122 kg (wet) by the end of the current fiscal year (1993). Selection of technologies for work to date was driven by the following criteria:

- Reduce Mass
- Reduce power consumption
- Reduce flight time
- Keep cost and risk within the mission context
- Level of existing activity in a technology area

Telecommunications

Several areas in the telecommunications subsystem have been identified where significant mass and power savings can be achieved with the insertion of new technology. Design and fabrication has begun for a low-mass, 1,5 meter parabolic antenna utilizing a new Honeycomb hybrid reflector design to reduce 3.5 kg from the mass allocated in the FY92 (5.8 kg) baseline which utilized a spare Viking antenna. The hybrid antenna will employ a dual X-band/Ka-band feed.

Attractive power and mass savings can be obtained for the Solid State Power Amplifiers (SSPA) utilizing pseudomorphic high electron mobility transistors (PHEMT) technology. Work is in progress to demonstrate a 1.5W Ka-band output power module with 30% power added efficiency (PAE) and 6dB of gain. Advanced 0.15μm PHEMT devices will be utilized. Ka-band allows for greater data rates and more science return over the 3W, 25% PAE FY92 X-band baseline. For our FY93 baseline a dual X-Ka-band downlink system is under consideration. The FY92 baseline calls for an amplifier using metal semiconductor field effect transistors (MESFET) producing 3W, X-band, ,9 kg mass and 2S % efficiency.

Advanced monolithic microwave integrated circuit (MMIC) and multi-chip module (MCM) packaging technologies arc the kcy to reducing the receiver portion of the transponder mass by

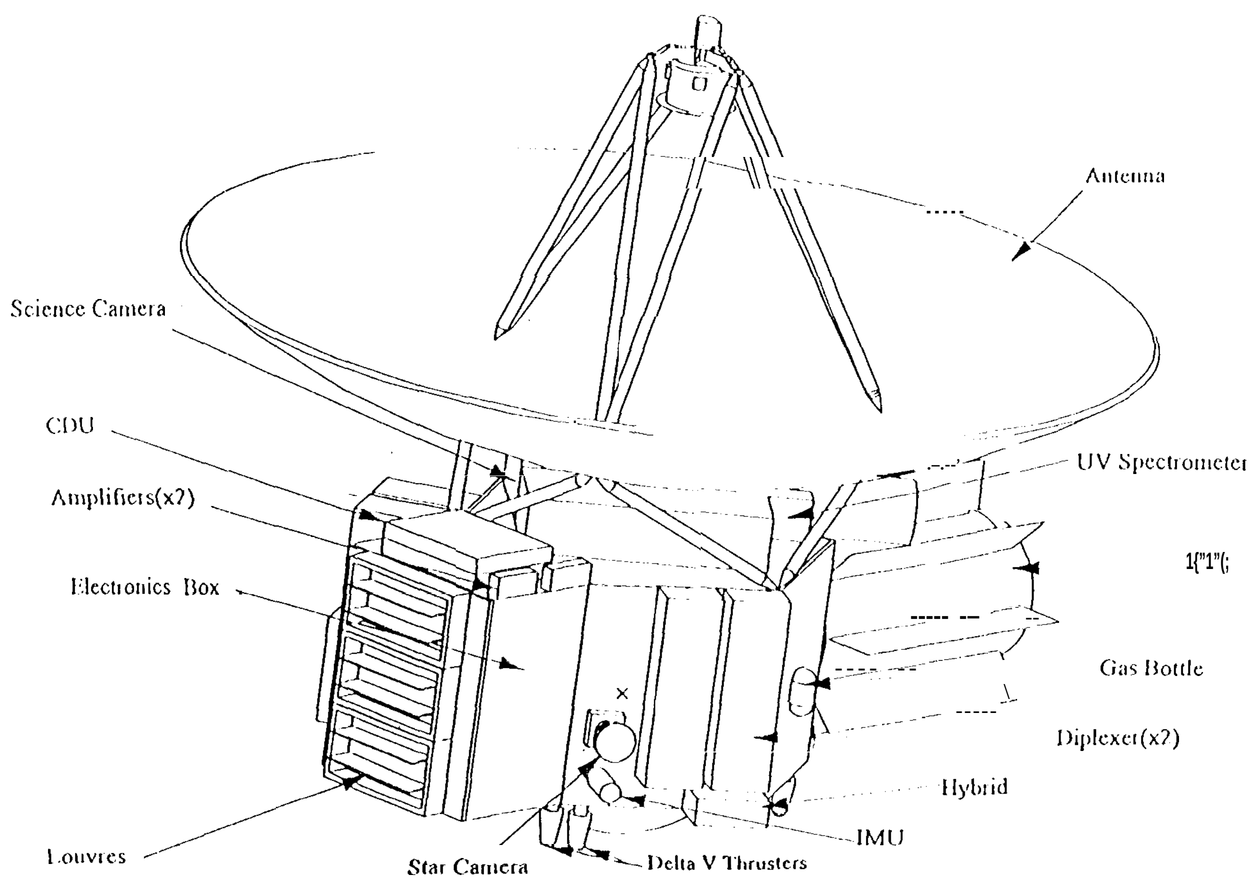

Fig. 1 1992 Configuration

50% and increasing functionality to include the Command Detector Unit, eliminating a separate physical module. Prime power may be reduced by elimination of unnecessary functions, intelligent frequency planning, new device technology and the possibil ity of using a transceiver versus a transponder. The latter is a navigation issue being addressed where coherent, two-way ranging might be replaced with less precise ranging plus greater reliance on optical navigation.

Power

The Electrical Power and Pyrotechnics Subsystem consists of a radioisotope power source (RPS) to generate power, power electronics for voltage conversion, regulation, transient peak power output, switch ing and fusing, and pyrotechnic device initiation (explosive bolts, pyro-valves, etc.).

The 1992 baseline design has a mass of 23.2 kg and generates 63,8 Watts of power after 9 years of operation. Power generated bya radioisotope thermoelectric generator (RTG) which uses five general purpose beat source (GPHS) modules. Power consumption of 64.4 Watts during the encounter mode includes 20% cent ingency for expected power growth as the design matures. Approximate] y 15 Watts is lost in DC-DC conversion and regulation inefficiency during the b ighest power modes. The current best estimate for power consumption during downl inking post-encount er (the h ighest power mode) is 52..31 Watts leaving a meager 22% contingency and margin witbin the 63.8 Watts power capability. An additional 10% margin is needed in most modes to account for uncertainties in the design process, the decay of the power source and the aging of the spacecraft as a whole.

Advanced technology being considered fOr the 1993 baseline design could reduce the mass of the subsystem to ~ 14 kg for the same power output. Technologies such as alkali metal thermo-electric converters (AMTEC) are being considered which could dramatically increase the efficiency of the RI'S, generating the same amount of electrical power using two general purpose heat source modules. A near prototype AMTEC cell that produces 3W with 1 O% efficiency has recently been developed and delivered to the Pluto team at JPL. Through additional development, a 3W, 16% efficient cell is expected to be delivered by the end of fiscal 1993.

Other work is on-going with thermophotovoltaic (TPV) converters that convert infrared radiation from the hot surfaces of two GPHSs to electricity using low bandgap photovoltaics. A number of lifetime and risk issues need to be resolved with TPVs before incorporation into the baseline. To begin addressing these concerns, the Pluto ATI program is sponsoring the first scale model demonstration of a simulated GPHS/TPV system. Tests should be complete by the end of 1993. Both AMTEC and TPV systems require a substantial development commitment to be available for the Pluto project by the 1995 technology freeze date.

Attitude Control

The attitude control subsystem (ACS) includes sun and star sensing devices, an inertial reference unit (IRU), electronics for interfacing with the central computer in the command and data subsystem, and electronics and switches to drive the thrusters in the propulsion subsystem. The star sensing device or star camera, with its software, can determine the spacecraft's three dimensional orientation by imaging star fields and comparing them with a catalog of stars in the computer's memory. The two sun sensors are used to help recover orientation in the event of a star camera failure. By commanding the small cold gaseous nitrogen thrusters in the propulsion subsystem, the attitude control subsystem can change or maintain the spacecraft's orientation, The 1992 baseline design has a mass of 2.7 kg and consumes 11.5 Watts of power.

New technology for a star camera weighing 500 grams may be feasible by May, 1995 with a substantial development commitment now. Related star camera activities are currently underway at Lawrence Livermore National Laboratory with their Clementine Project and it is hoped that lessons learned there and new technology development by industrial vendors can be implemented into the Pluto flyby mission. A primary concern is qualification for the roughly decade-long mission.

Additional savings in mass and power consumption are currently being investigated in the breadboard stage elsewhere for a low-mass IRU.

Command and Data

The command and data subsystem includes the central computer and its memory, the mass storage memory, and the necessary input/output devices for gathering data from and commanding other subsystem. The computer executes algorithms for attitude control, sequencing, propulsive maneuvers, fault protection, engineering data browse and reduction, and other data management functions. The mass memory is used to store all the near encounter science data for transmission to Earth post-encounter, and to store engineering data between ground communications cycles during the entire mission. in the 1992 baseline the subsystem had aggressive mass and power targets of 7,0 kg and 6.0 Watts during encounter, Total science data storage volume was 400 Mbits.

Use of advanced technology in electronics packaging and low power interface drivers is expected to achieve the mass and power targets for the 1993 baseline design while increasing science data storage volume to as much as 2 Gbits. The FY93 baseline design is based on an SCI FTP-3200 computer, The redundant electronics have a mass of 5.S kg and would Operate at 11 W at encounter. Work is continuing to reduce power requirements by investigating low power I/O bus structures.

Structure

The structure subsystem includes the primary and secondary structure of the spacecraft and separation systems. It must support all of the spacecraft components during the vibration and acceleration of launch and injection by the upper stages. The structure helps shield the electronics from the natural and RPS induced radiation environment. The 1992 baseline features an all aluminum primary structure with a mix of aluminum and graphite-epoxy composite members in the secondary structure utilizing procedures and processes proven in space applications.

An ATI contract has been awarded for a composite bus structure development model that is expected to demonstrable valuable design insights leading to significant progress toward mass reduction saving an estimated 5 kg in the primary structure. Development is now proceeding with a new spacecraft configuration providing more direct load paths, improved mass balance and lower thermal impact from the RPS. The secondary structure ATI also supports some of the issues taken up in the section on thermal control,

Propulsion

The propulsion subsystem consists of a monopropellant hydrazine thruster set for providing the required trajectory corrections, plus cold-gas thruster attitude control equipment. A hybrid, blow-clown system was adapted using a portion of the hydrazine tank pressurant gas as the working fluid for the cold-gas thrusters,

The principal objectives in the RFI were reductions in subsystem mass, gas leakage, and power consumption. From the industry responses to the Request for information, it became apparent that reductions in mass up to factor of five could be realized in several components. Miniaturization of the pressure regulators and valves (service and latch), use of a composite

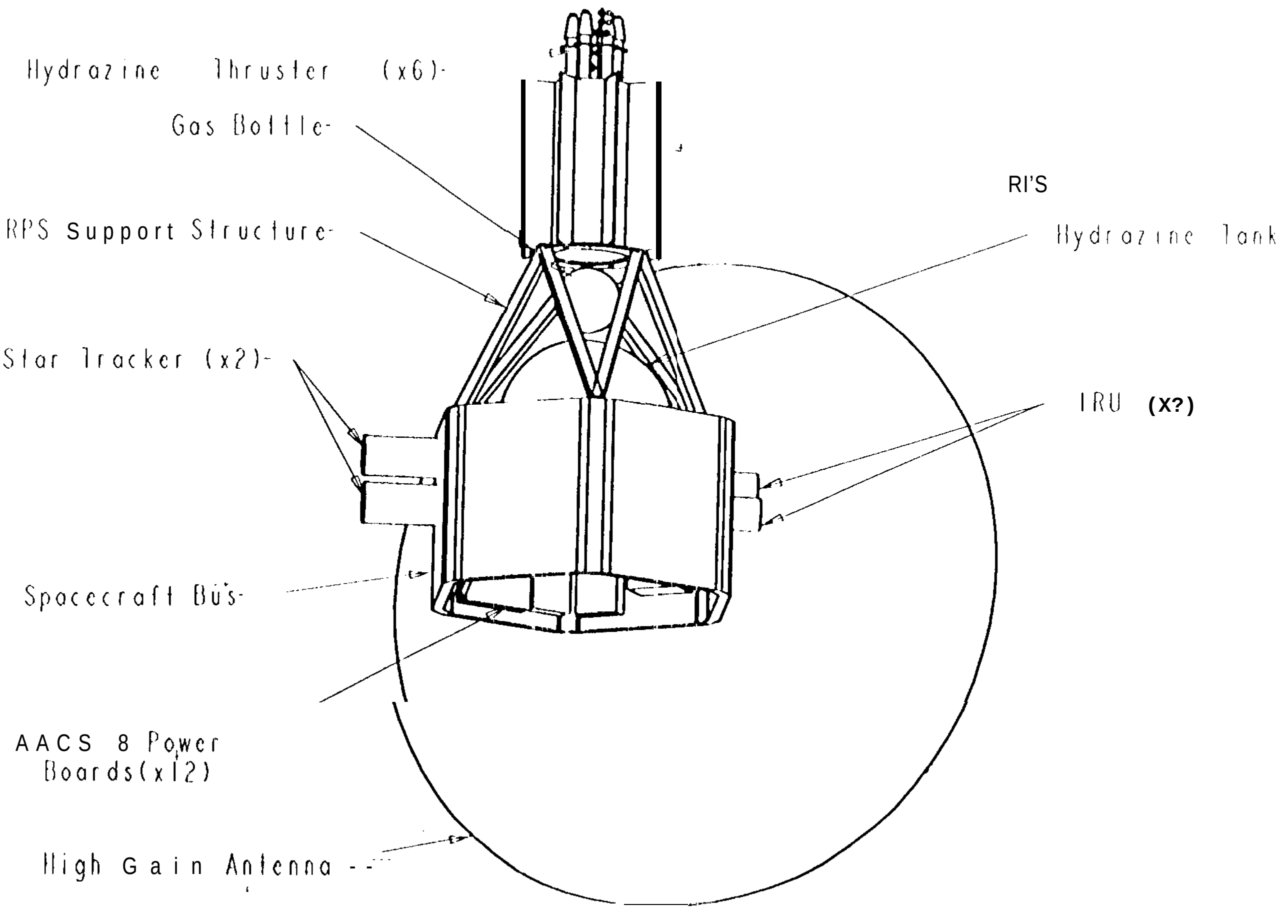

Fig. 2 1993 Configuration (preliminary, subject to change).

over-wrapped pressurant/propellant tank as used in the fourth stage of the air-launched *Pegasus*, and a surface tension propellant management device (PMD) were identified as technologies of interest for the Pluto mission. Also identified was a miniature (0.0045 N) cold-gas thruster with improved internal leakage (factor of ten decrease) and cycle 1 ife (2.9,000 increase) specifications and a wider operating temperature range specification. Thruster valve actuation and holding power would also both be reduced.

With improvements in the injection accuracy, through 3-axis stabilization of the upper stages, significant reductions in the required mass of hydrazine monopropellant could occur, reducing, the subsystem mass to under 10 kg.

The miniature cold-gas thruster approach meets the thrust, response time, and minimum impulse bit requirements for the Pluto mission and the GN_2 exhaust minimizes potential spacecraft impingement problems. The ATI internal leakage and cycle life requirements will have to be demonstrated for the approach to be considered a viable one.

Thermal Control

This subsystem is basically passive, consisting of blankets, louvers, radiators, and other thermal control paths and insulators, Radioisotope heat sources (RHS) provide heat to the delta-V thrusters and may also be required to help keep the spacecraft warm during cruise. Multilayer insulation (Ml .1) blankets made from embossed Kapton® or Mylar® material will minimize thermal energy transfer between elements of the spacecraft. Thermal conduction control, such as the thermal isolation between the spacecraft and the antenna, and thermal enhancement allowing more effective energy conduction from the electronics to radiators that arc designed to transfer excess heat from the RPS, keep all tile subsystems within tolerable temperatures. Mechanical louvers actuated by a bimetallic device have good radiative properties in the open position and help to hold heat in when in the closed position.

in the. 1992. basel inc design the mass of the subsystem is 4.0 kg. Power consumption will not exceed 1 Watt for heaters. The usc of advanced technology, like high conductivity coatings and structural materials, may help to reduce the mass and decrease the temperature transients experienced by the subsystems.

Mission Operations

The mission operations for the Pluto Fast Flyby mission is investigating two possible low cost approaches during the ATI phase,

The first approach uses a migration of function approach by utilizing the *Voyager **flight*** team to fly the two Pluto spacecraft as well. The *Voyager* team has proven their ability to conduct successful planetary fl yb y operations and would be supplemented with selected Pluto specialists in the areas of mission planning, navigation, inst ruments, and spacecraft. Th is combined approach would draw heavily on JPL's Advanced Multimission Operations System (AMMOS) which is supporting current *Voyager* operations.

The second low cost operations approach being evaluated has been developed under a JPL contract at the University of Colorado (CU), Boulder. in this approach, JPL would provide Deep Space Network (DSN) tracking and navigation, and CU would develop a simple and unified mission operations data system as a network of operat ions stations at JPL, universities, and science investigator facilities. Routine operations would be accomplished by a remote-site operations team of students and professionals with JPL experts extending the operations team for critical or anomalous events and advising the university students. The primary, JP1.-hased, control center would direct the encounter and other critical events, and each site would serve as a backup to the other.

Additional reductions in operations costs can be real ized by applying technological advances in the development phases of the strawman instrument package, spacecraft, mission and ground operations design that permits long periods of unattended operations during cruise. Eight hours of tracking and data collection per week would be made using the DSN to check upon the two spacecraft with the following attributes:

- a spacecraft engineering data return strategy that takes advantage of on-board data processing and analysis to minimize the amount of engineering data that needs to be downlinked and analyzed;
- spacecraft command and control capabilities that allow cruise commands to be uplinked without simulations and elaborate constraint checking;
- an encounter/flyby command sequence that pre-planned and tested during cruise and is only "tweaked" immediately before closest approach to allow for mosaic retargeting and arrival time uncertainties;
- capable on-board data management that permits capture and storage of all the science data collected during flyby and allows for on-board select ion, compression, and return over a limited downlink (40 to 160 bps) via daily DSN passes for up to a year after the flyby;

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- early and continued interaction among the operations and data system design teams, the science investigator team, and the spacecraft design team to ensure that the Pluto mission operations and data system is specifically tailored, developed, and evolved to meet the needs of its users at lowest possible cost;

- a progressive development philosophy where the basic mission operations and data system is developed at the start of the project; used to support prelaunch development, subsystem test, spacecraft test, calibration, and post-launch operations; and progressively grown to meet the needs of these project phases and users; and

- a unified operations system architecture that facilitates the migration of functions from the ground to space and enables trades between flight- and ground-based functions by inducting both flight and ground data systems as part of the integrated end-to-end mission operations and data system.

Further developments of a single ground data system would allow using the same terminals and workstations which could be configured to operate either of the two missions throughout their life cycle.

Student Involvement

Pluto Mission Operations would have an educational dimension. Students - advised by Pluto science investigators and JPL experts, and supervised by experienced professionals - would staff many of the operational positions as with Solar Mesosphere Explorer [4]. Engineering data and compressed science data would be accessible by schools across the country. The operations workstations at JPL, universities, and science user sites would be set up to encourage student participation and visibility. The distributed operations data system would exploit international standards for the interfaces among user sites and operations stations, and therefore would offer the opportunity for cooperation with other institutions, nations, and schools. Lessons learned at CU operating the Solar Mesosphere Explorer (SME) Mission [4] would be applied toward achieving such a low cost system with its

PLUTO FAST FLYBY

STUDENT ACTIVITY STATUS

August ?4, 1993

-Allocations for FY93 student projects:
- -$110K from Code C funds
- -$57K from Code S funds

-The stats:
- -84% of the money went out to schools/ students
- -18 schools involved (non-funded research not shown in table below)
- -3 schools are minority institutions or HBCUs
- -over 40 students are significantly involved with Pluto Fast Flyby world-wide

Subsystem	University	Project
Telecom	U of Michigan	Build low-loss power divider
Instruments/ S/C System	Caltech/ N. Az. U. (MI)	Payload design, s/c mockup
Structure/ bus	Utah State U	Build isogrid bus structure
End to End Info. System	Central State U (HBCU)	Build data flow architecture sim.
Structure	Harvey Mudd	Design and build stack adapters
Flight Computing	U of Baltimore	Recomend data compression
Propulsion/ Stack	Caltech	Build stack motor mockups
Flight Computer	Stanford	Build low power CMOS chip
Trajectory/ Science	Occidental College	Animation of Pluto/ Charon flyby

Table 3. Student Involvement in the Pluto Mission

PLUTO MISSION ATI CONTRACTS

INSTRUMENTS

Stanford University, Stanford, CA
  Len Tyler, PI — Uplink Radio Science Instrument
Johns Hopkins University/Applied Physics Laboratory, Laurel, MD
  Ultrastable Oscillator (USO)
University of Colorado, Boulder, CO
  George Lawrence, PI — Ultraviolet Spectrometer
Southwest Research Institute, San Antonio, TX
  Alan Stern, PI — Integrated Pluto Payload System
Ball Electro-Optics/Cryogenics Division, Boulder, CO
  Infrared and Visible Subsystems
Westinghouse Space Division, Baltimore, MD
  Bruce Nichols, PI — Instrument Package Miniaturization Program
Goddard Space Flight Center, Greenbelt, MD
  Don Jennings, PI — Linear Etalon Imaging Spectral Array
U.S. Geological Survey, Flagstaff, AZ
  Larry Soderblom, PI — Integrated UV/VFR/IR Instrument
• The Aerospace Corporation, Los Angeles, CA
  George Rossano, PI — Low-mass, low-power Visible Imaging System and IR Mapping Spectrometer
Washington University, St. Louis, MO
  W. H. Smith, PI — Pluto Reflectance Imaging Mapping Interferometric Sensor

SUBSYSTEMS

• Environmental Research Institute of Michigan, Ann Arbor, MI
  Prototypic Alkali Metal Thermal-to-Electric Conversion (AMTEC) System Cells
• Advanced Modular Power Systems, Ann Arbor, MI
  Prototypic Alkali Metal Thermal-to-Electric Conversion (AMTEC) Cells
• Boeing Defense and Space Group, Kent, WA
  Thermophotovoltaic Thermal-to-Electric Conversion Development
• Martin Marietta Astrospace, King of Prussia, PA
  Ka-band Solid State Power Amplifier
• SCI Systems, Inc., Huntsville, AL
  Computer module
• Composite Optics, Inc., San Diego, CA
  Bus Structure Engineering Development Model
• Boeing Defense and Space Group, Kent, WA
  Telecommunications Antenna
• Futurecraft Corporation, City of Industry, CA
  Service Valves
• Moog, Inc., East Aurora, NY
  Cold-gas Thruster

OPERATIONS

• University of Colorado/Colorado Space Grant Consortium, Boulder, CO
  Mission Operations Concept, and Development software

OTHER CONTRACTS

• Altadena Instruments, Pasadena, CA
  Instrument Data Architecture
• JRF Engineering, La Cañada, CA
  Engineering and Rapid Development consulting

Table 4. ATI Contracts Awarded

educational and science team benefits,

University students have already been involved in the initial preproject development stages and will continue to be an important part of the Pluto team through to the end of the mission. Students from Caltech and other institutions built the first full-scale mockup of the spacecraft as the very first deliverable hardware. A competition among universities to design an adapter that unites the spacecraft to the upper stage solid rocket motors (SRMs) is under way. Mockups of the upper stage SRMs with their adapters are also being built by students.

Summary and Conclusions

A list of ATI contractors selected during FY93 appears in '1'able 3. In addition, some resources from the Office of Space Science's Planetary instrument Definition and Development Program (1'1111>1') have been directed toward developing and demonstrating technology applicable to the Pluto payload. Flight equipment will be procured under later procurement actions separate from the ATI procurements.

A scientifically exciting initial reconnaissance of Pluto and Charon is possible within a strict cost cap. Technologies pioneered for small Earth orbiters, and in some cases advanced further through NASA support for the Pluto mission, enable spacecraft mass and operations cost reductions far below what was thought possible as little as two years ago. Present efforts are focused on demonstrating the viability of new subsystem and instrument components, and an innovative development, test and operations approach, through procurement and testing of proof-of-concept hardware and software. Mission resource constraints are being tightened even further, so recent work represents a head start toward reaching aggressive goals of cost and technology improvement within a first-class scientific mission to unexplored Pluto and Charon.

Acknowledgements

The work described here. was carried out at the Jet l'repulsion Laboratory, California Institute of Technology under sponsorship of NASA's Office of Space Science and the Office of Advanced Concepts and Technology.

The authors are grateful to all the Pluto Team members and contributors, and for the considerable assistance from their respective institutions, including NASA Lewis Research Center, U.S. Department of Defense, U.S. Department of Energy, Southwest Research Institute, Science Applications international Corporation, University of Colorado, Boulder, University of California, 1 .os Angeles, University of Baltimore, University of Arizona, Occidental College, Harvey Mudd College, Utah State University, the contractors noted in "1'able 3, members of the '1'ethnology Challenge 'Ram chaired by Dr. Lew Allen, and the Outer Planets Science Working Group, chaired by S. Alan Stern.

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